The Nuclear Equation of State*

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We present a discussion of the zero-temperature equation of state of nuclear matter predicted by the Thomas-Fermi model of [1]. The equation is in the form of a three-term polynomial in the cube root of the density, with coefficients that are functions of the relative neutron excess . The coefficients are tabulated in the range from $\delta = 0$ (standard nuclear matter) to $\delta = 1$ (neutron matter), making it very easy to calculate, for a given δ , the pressure, compressibility, saturation binding and any other property of the Thomas-Fermi equation of state. We discuss the empirical information concerning abnormal densities and large neutron excess that is contained in the measured values of the surface energy, surface diffuseness and the neutron skin.

There is currently considerable interest in the energy per particle of nuclear matter, $e(\rho, \delta)$, considered as function of the nuclear density ρ and the relative neutron excess δ, where $\delta = (\rho_n - \rho_p)/\rho$. This fundamental quantity, the equation of state at zero temperature, plays a key role in theories of neutron stars and supernova explosions, as well as in the interpretation of nucleus-nucleus collisions at energies where nuclear compressibility comes into play. (For a review and references see, for example, [2].)

Direct information on $e(\rho, \delta)$ is difficult to come by for values of ρ away from those characterising normal nuclei and for δ beyond the relatively small values characteristic of the most neutron rich stable nuclei. One way to extrapolate beyond this limited regime is by using a nuclear model fitted to binding energies of finite nuclei and then applying the model to nuclear matter. In order to be reliable, such an extrapolation should be based on a well-founded, robust theory with as few adjustable parameters as possible, the theory being fitted very precisely to measured binding energies and other relevant properties, and subsequently tested for its predictive powers under conditions not included in the determination of the parameters. We have recently completed a Thomas-Fermi model of nuclei that attempts to satisfy these requirements [3] , and in the present paper we describe the model's predictions concerning the equation of state $e(\rho, \delta)$.

The model is based on the semi-classical Thomas-Fermi approximation of two fermions per h^3 of phase space, together with the introduction of a short-range (Yukawa) effective interaction between the particles. The strength of the interaction (different between like and unlike nucleons) is a function of the relative momentum of the interacting particles and of the densities at the particles' locations. There are altogether 6 relevant adjustable parameters which were fitted to 1654 measured binding energies and to the measured diffuseness of the nuclear surface.

Without readjusting the fitted parameters, the resulting model was found: a) to reproduce measured nuclear sizes, b) to extrapolate correctly to light nuclei with $N, Z < 8$, not included in the parameter fit, c) to extrapolate correctly to masses of strongly deformed fission saddle-point shapes, and d) to predict the density dependence of the energy of neutron matter in substantial agreement with independent theoretical estimates.

*Extracted from Ref. [4]

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